

Alternative Fuel Transit Buses

Fuel Economy

Fuel economy and fuel costs are very important to transit agencies because the fuel cost represents a large portion of the operating cost of a transit bus. Excluding driver labor costs, the fuel cost is approximately half of the operating cost of a diesel bus, and more than half for some alternative fuel buses. The average monthly in-use fuel economy was calculated from the fuel added and odometer reading each time the bus refueled. The fuel economy often varied from month to month.

Miles to go Before We're Done

The goal of the program is to gather sufficient data on ten buses for each fuel type, with five buses at one site and five at another. At this time, the program is approximately half complete. Some sites have reported a substantial amount of data; others have just started to report data. Differences often emerge between sites as a result of different experience with the buses, different operating conditions, and different reporting procedures. Care should be taken in drawing conclusions from the program at this time. The amount of data included in the analysis for the final report will approximately double—an increase that should substantially enhance the validity of all results and findings.

Total Mileage of the Test Buses

Site	Alternative Fuel	Months of Data	Total Mileage on Alternative Fuel Buses
Houston, TX	LNG	17	376,000
Tacoma, WA	CNG	14	294,000
Miami, FL	CNG	17	87,000
Peoria, IL	E93*	23	389,000
Minneapolis/ St. Paul, MN	E95	9	57,000
Miami, FL	M100	17	193,000
New York, NY	M100	0	0
St. Louis, MO	BD20	9	165,000

* Fleet started on E95 and then switched to E93

Figure 5 shows the range of monthly average fuel economy for the alternative fuel and diesel buses at each site. The fuel economy is expressed as miles per diesel equivalent gallon. A diesel equivalent gallon is the quantity of alternative fuel that has the same energy content as one gallon of diesel fuel. Expressing the fuel economy in miles per diesel equivalent gallon allows for a direct comparison of the relative energy efficiency of the various alternative fuel engine technologies.

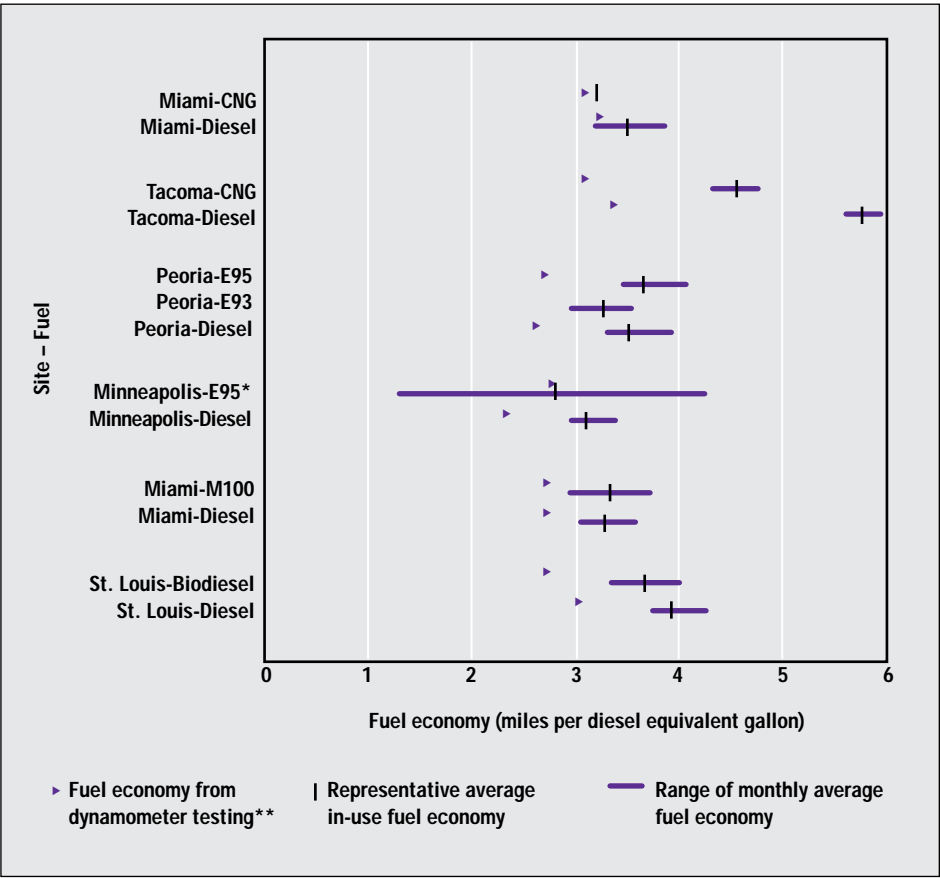
The spread in the fuel economy data is different for each site. This variability may result from differences in driving cycles from bus to bus and from site to site.

Periodically, the test buses were removed from service and emissions tested using a chassis dynamometer. During these tests, the fuel economy of the buses was also measured. These dynamometer results (which were all obtained using the Central Business District driving cycle) are shown as triangular points in Figure 5. The fuel economy measured using the dynamometer was relatively consistent throughout each test fleet. This indicates that the variations in the in-use fuel economy results are probably due to driving cycles. Because the dynamometer results are consistently below the average in-use results, the Central Business District driving cycle may not be representative of the actual driving cycles of the test buses. The sections that follow summarize fuel economy by fuel type.

Liquefied Natural Gas

The Houston buses use DDC 6V92 PING engines, which operate on a compression-ignition cycle using diesel fuel as the “pilot ignition” source to ignite the natural gas. The average fuel economy for these buses (not shown in Figure 5) was calculated by summing the amount of LNG (in diesel equivalent gallons) and diesel burned in the buses over time, and dividing that sum by the total miles logged. The average fuel economy for the LNG buses (3.1 miles per diesel equivalent gallons) was approximately 14% less than that of their diesel counterparts. A small part of this reduction is due to the approximately 860 pounds of extra weight of the LNG/diesel dual-fuel buses, but the majority is most likely attributable to engine operating problems (see maintenance section), differences in driving cycles, or LNG measurement inaccuracies. When the dual-fuel buses were operating in their “backup” mode of diesel only, the fuel economy was within 4% of that of the control buses.

Since the beginning of the program, the PING engines used in Houston have been removed from the market in favor of a new engine design—the DDC Series 50G. Houston has plans to use the Series 50G engine in some buses running on LNG. We are in the process of adding a second site with LNG buses to the program. The additional buses will run on spark-ignited throttled engines rather than PING engines.



Compressed Natural Gas

The CNG engines operating in Miami and Tacoma are spark-ignited throttled engines; the diesel engines are unthrottled compression-ignition engines. When a diesel compression-ignition engine is redesigned into a spark-ignition engine running on natural gas (as is the case with all the CNG engines in the program), there is an inherent loss of efficiency because of pumping losses. Pumping losses represent the amount of energy required for the engine to draw in air during the intake cycle. An unthrottled diesel engine has minimal pumping losses, whereas a spark-ignited engine with a throttle has significant pumping losses. In addition, the CNG engines have a

Figure 5. Fuel economy of the test buses***

* During cold weather the ethanol buses in Minneapolis are left idling overnight to assure smooth operation in the morning. This leads to the wide range of fuel economies shown in the figure. The average warm weather fuel economy of these buses is about 3.5 miles per diesel equivalent gallon. The average warm weather fuel economy of the diesel control buses is about 3.2 miles per gallon.

** The triangular points represent the fuel economy from chassis dynamometer testing using the standard Central Business District driving cycle.

*** The LNG fuel economy is not shown because the data are insufficient to calculate the range of monthly in-use fuel economy.

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lower compression ratio than their diesel counterparts: 10.5 to 1 for the CNG engines versus 16.3 to 1 for the diesel engines, which also tends to lower efficiency.

An added disadvantage for the CNG buses is their weight—they weigh about 3,900 pounds more than their diesel counterparts. This weight penalty results largely from the weight of the CNG tanks, and increases the curb weight of a bus by about a 14% (the diesel control buses have a curb weight of approximately 27,000 pounds). These three factors led us to expect that energy efficiency might be significantly reduced. A difference in the fuel economy of the CNG and diesel buses was observed both in the average results and the dynamometer results. The fuel economy of the CNG buses was about 10 to 20% lower than that of their diesel counterparts.

Alcohols

The alcohol buses also suffer from weight penalties. The alcohol option results in a weight penalty of between 1,000 and 1,500 pounds, depending on the fuel tank capacity. In addition, the alcohol buses at the Miami site have an additional weight penalty of 1,200 pounds, which is partially due to options and specifications unrelated to the alcohol fuel engine. We expected this extra weight to reduce the fuel economy of the alcohol buses.

In addition, the alcohol buses have very high compression ratios (more than 20 to 1), which was expected to lower fuel economy because of higher friction losses (such as piston

side loading). The results to date, however, indicate that the alcohol fuel buses at all the sites are performing very well, delivering fuel economy comparable to that of the diesel control buses on an equivalent energy basis. (Note that the diesel control buses at Peoria are equipped with particulate traps, which are known to lower fuel economy slightly.)

Biodiesel

The St. Louis biodiesel buses exhibited approximately 6% lower average fuel economy than the diesel control buses. Dynamometer data also showed a similar drop in fuel economy. Because the fuel economies quoted are already based on diesel equivalent gallons to eliminate any differences in fuel energy content, we did not expect this drop. We are currently investigating the cause of this drop.

In summary, the fuel economy results are in line with expectations from the various engine technologies, with the possible exceptions of the LNG dual-fuel engine, and the biodiesel buses, where the reason for the lowered fuel economy is not readily apparent.

Costs

The cost of operating alternative fuel buses versus their diesel controls can be broken down into operating and capital costs. These categories can, in turn, be broken down further. Operating costs consist of fuel, oil, maintenance, and repair costs. Capital costs consist of the additional costs of the alternative fuel bus and